SHOCK EFFECTS ON PHASE Q AND HL DIAMONDS INFERRED FROM EXPERIMENTAL SHOCK LOADING ON ALLENDE METEORITE.

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Impact events on the planetary bodies in the early solar system are a fundamental process that affected on physical and chemical properties of the primitive chondritic materials. Volatile elements such as H_2O, CO_2 and radiogenic Ar are known to be lost by impacts from chondritic meteorites [1, 2] and volatile-bearing minerals [e. g., 3]. Experimental studies concerning shock effects on noble-gas abundance have been done mostly on the radiogenic Ar [e. g., 2, 4], but little is known about shock effects on primordial noble gases. In the early stage of the solar system formation, predominant noble gases in the planetary bodies were the primordial ones that had been incorporated during formation of these bodies. Major components of the primordial noble gases are Q-gas and HL-gas. The former dominates primordial Ar, Kr, and Xe, and the latter comprises most of primordial He and Ne [5]. The two types of primordial noble gases are sited in different carrier phases; ill-identified carbonaceous matter called phase Q for Q-gas [e. g., 6] and tiny diamonds of interstellar origin for HL-gas [e. g., 7]. These two carrier phases are found to be distributed in any type of primitive chondritic meteorites [8]. Therefore, shock effects on phase Q and HL diamonds are essential issues to be addressed, in order to elucidate effects of impacts on noble gas abundance in the primitive planetary bodies.

A series of shock-recovery experiments were performed on the Allende CV3 chondrite, which is rich in primordial noble gases, with peak pressures of 30, 47, and 70GPa using a single stage propellant gun. To avoid adsorption and implantation of atmospheric noble gases, Allende sample was preheated to ~180 C for 4 hours in the gun chamber, ambient air was replaced by N_2 gas during cool down the sample, and the sample was evacuated down to $1 \sim 4 \times 10^{-2}$ torr through a vent in a stainless sample holder. The recovered samples were examined using an electron microprobe and analyzed for noble gas composition using a noble gas mass spectrometer by a stepped heating technique with eight temperature steps, 350, 450, 600, 800, 1000, 1250, 1550, 1850 C.

Petrological observations: Cross sections of the Allende samples shocked at 30 and 47GPa exhibit a high degree of porosity reduction of matrix and flattening of chondrules, which is consistent with results of experimental shock-loading on Allende in a previous study [9]. Fine-grained olivine, low-Ca pyroxene, Fe-Ni metal and sulfide in the matrix of the 30GPa product appear not to be melted, whereas those in the 47GPa product are melted in some portions, where metal and sulfide grains became rounded. An Allende sample shocked to 70GPa shows a drastic petrological modification: matrix is totally melted, numerous small gas bubbles with diameters from 1 to 30 μm are generated, and chondrules are partially melted and disaggregated. The melt of matrix containing high densities of the bubbles intrudes into cracks in a metallic sample holder.

Noble gas analysis: All noble gases (He - Xe) were measured in the three shock-loaded products and a natural Allende sample for reference. Measured noble gases were separated into primordial, radiogenic, and cosmogenic components using reported isotopic ratios of these three components [e. g., 10]. Moreover, primordial ^{20}Ne and ^{132}Xe amounts were separated into Q- and HL-gases, i. e., $(^{20}Ne)_Q$ vs. $(^{20}Ne)_{HL}$, and $(^{132}Xe)_Q$ vs. $(^{132}Xe)_{HL}$, using Xe-Q, Xe-HL isotopic ratios [6, 11] and a $(^{20}Ne/^{132}Xe)_Q$ elemental ratio [11]. Results of the stepped heating analyses show that noble gases in 350 C fractions in all four samples were dominated by absorbed or implanted air except for He, thus Ne - Xe in the 350 C fractions are excluded from total amounts of released noble gases.

Concentration of heavy primordial noble gases such as ^{36}Ar, ^{84}Kr, and ^{132}Xe decreases in the order of unshocked Allende, 30, 47, and 70GPa samples: $(^{132}Xe)_Q$ concentrations are 9.4, 6.9, 5.9, and 2.4×10^{-10} cc STP / g, respectively. This indicates that phase Q lost up to 75% noble gases due to experimental shock-loading. Release patterns of $(^{132}Xe)_Q$ of unshocked Allende, 30, 47, and 70Gpa samples are basically similar, although gas-amounts of each temperature step are reduced, suggesting heterogeneous shock effects. Phase Q which suffered heavier shock effects lost all noble gases including gases in highly retentive sites, while that suffered lesser degree of shock effects retained most noble gases. A slight difference in the release patterns is seen between unshocked and shocked (30 and 47GPa) samples. The latter shows a small peak at an 800 C temperature step. This fact might indicate that minor parts of phase Q change gas-retentivity by impacts. Similar features are also observed in analyses of both experimentally shocked Allende at 23GPa [12] and the Leoville CV3 chondrite [13] which experienced shock pressure ~ 20GPa in space [14].

Unlike phase Q, HL diamonds did not lose noble gases by shock loading. Amounts of HL-gases such as $(^{20}Ne)_{HL}$ and $(^{132}Xe)_{HL}$ were relatively constant in the unshocked and shocked samples: $(^{20}Ne)_{HL}$ concentrations are 2.2, 2.9, 2.5, 2.1 x 10^{-10} ccSTP / g for unshocked, 30, 47, and 70GPa samples. Release patterns of $(^{20}Ne)_{HL}$ from all the four samples are also similar. Thus, HL diamonds appear to keep concentration and gas-retentivity of noble gases, even after 70GPa shock. Large amounts of HL-gas were extracted in 800 - 1000 C fractions in the stepwise heating experiments, whereas Q-gas has a largest extraction peak at 1250 C, indicating that HL diamonds are weaker to thermal effects than phase Q. However, in contrast, HL diamonds are stronger against shock effects than phase Q. The reason why HL-gas was not lost by a strong shock compression is uncertain, but HL-gas is likely to be rigidly trapped in the crystal structure of diamonds. As a results of preferential loss of Q-gas from shocked samples, remained noble gases tend to have higher ratios of HL / Q, resulting in a change of isotopic ratios especially those of light and heavy Xe isotopes.

Radiogenic ^{40}Ar seems to be unaffected by 30 and 47GPa shock loading. Two large extraction peaks at 800 and 1250 C, which observed in the analysis of unshocked Allende sample, are observed in analyses of both 30 and 47GPa samples. But, the 70GPa sample shows apparent decrease of released-^{40}Ar amounts in low temperature fractions, 450 - 800 C. Coupled with the results of petrological observations, the ^{40}Ar loss from the 70GPa sample is due to diffusive loss from matrix material that was totally melted by the effects of 70GPa impact. But, the 1250 C peak was still observed in the 70GPa-sample analysis, which is consistent with the petrological observation that most chondrules in the 70GPa sample suffer only partial melting. The same tendency was observed in the extraction of cosmogenic noble gases: concentrations of cosmogenic ^{21}Ne and ^{38}Ar in the unshocked Allende, 30, and 47GPa samples were relatively constant, but those in the 70GPa sample decrease by approximately 50% in total amounts. The ^{21}Ne and ^{38}Ar loss is observed especially in the low temperature fractions, indicating diffusive loss from the matrix material, like the case of radiogenic ^{40}Ar.

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